

PARTITIONING OF CARBON DIOXIDE BETWEEN THE ATMOSPHERE AND LITHOSPHERE ON EARLY MARS; J.B. Pollack, J. Kasting (NASA Ames Research Center, Moffett Field, CA 94035), and S. Richardson (Iowa State University, Ames, Iowa, 50011)

There is limited geological evidence that Mars may have had a clement climate in its early history, perhaps one characterized by surface temperatures exceeding the freezing point of water (1,2). The most likely means of achieving a warmer, wetter climate is by an efficient greenhouse effect produced by a high pressure, carbon dioxide dominated atmosphere (1,3). In a comparison paper (4), we show that  $\text{CO}_2$  partial pressures at the surface ranging from 0.75 to 5 bars are required to raise the surface temperature above 273K, with this range of pressure depending on the choice of orbital location, latitude, season, and surface albedo. Here, we examine geological processes that remove and add atmospheric carbon dioxide, assess the feasibility of retaining a several bar  $\text{CO}_2$  atmosphere for extended periods of time ( $\sim 1 \times 10^9$  years) at an early epoch on Mars, and discuss the ultimate fate of such an atmosphere.

Carbon dioxide in the present atmosphere of the Earth has a residence time of only about  $10^4$  years due to the chemical weathering of continental Ca and Mg containing silicate rocks that ultimately convert atmospheric carbon dioxide into carbonate rocks (5). If the surface temperature on early Mars was above the freezing point of water, at least at certain seasons and places, the chemical weathering of rocks would undoubtedly cause a rapid loss of atmospheric carbon dioxide, thereby tending to greatly diminish the greenhouse effect responsible for the clement climate. We have estimated the time scale for the removal of an initially massive  $\text{CO}_2$  atmosphere by chemical weathering by appropriately scaling chemical weathering rates for the Earth and using empirical relationships for the dependence of these rates on pressure (6), temperature (7), and precipitation (7). We also allow for differences in the cation content of silicate rocks and the fractional area covered by standing bodies of water on the two planets and consider constraints imposed by heat balance considerations on the rate of evaporation and hence precipitation and by physical weathering on the rate of chemical weathering. According to our calculations, a several bar  $\text{CO}_2$  atmosphere would have a residence time of  $10^7$ - $10^8$  years due to chemical weathering. Although this time scale is a lot longer than that for the present Earth's atmosphere (due mostly to the larger mass of the putative early Martian atmosphere), it is still short compared to the time scales of greatest interest ( $\sim 1 \times 10^9$  years).

Although carbon dioxide has a short residence time in the Earth's present atmosphere, its loss is approximately balanced by the outgassing of  $\text{CO}_2$  from the Earth's interior. Much of the outgassed  $\text{CO}_2$  may be derived from carbonate rocks that have been subducted into the Earth's interior, where they are thermally decomposed. An analogous process may have existed on early Mars: global scale volcanism may have led to the efficient decomposition of carbonate rocks when hot lava came in contact with these rocks and especially when magma buried them to great enough depth where temperatures exceeded their phase stability boundaries. We have been able to estimate the time scale for such recycling from simple energy considerations: the interior heat flux at the surface is due to a combination of thermal conduction and latent heat released from surface magmas. Constraining the rate of volcanism to be a prescribed fraction of

the surface heat budget and using theoretical estimates of the surface heat flux for early Mars (8), we find that the time scale for recycling CO<sub>2</sub> by lava burial is comparable to the time scale for chemical weathering. Hence, through such a recycling mechanism, a large CO<sub>2</sub> atmosphere could have been maintained on early Mars for an extended period of time.

Ultimately, the recycling rate would have greatly declined due to both a decrease in the rate of surface lava production (due to a decline in the surface heat flux) and to its assuming a more regional character (hence carbonate rocks in only localized regions would be recycled). Therefore, during an intermediate epoch in Martian history, chemical weathering would have assumed a dominant role and the large greenhouse effect would have disappeared. However, it is conceivable that large amounts of CO<sub>2</sub> may have been reintroduced into the Martian atmosphere for comparatively short times ( $<1 \times 10^9$  years) during some portions of its later history at times of extensive volcanism that temporarily recycled CO<sub>2</sub> back into the atmosphere.

If chemical weathering played a key role in controlling the amount of CO<sub>2</sub> in the early Martian atmosphere and ultimately in removing much of it, then geologically significant quantities of carbonate rocks should have resulted. Even after liquid water could no longer exist in most places and at most times at the surface, transient pockets of liquid water may have continued to provide an environment in which atmospheric CO<sub>2</sub> could have been transformed into carbonate rocks, although at a much reduced rate (9). Thus, a search for the signature of carbonate rocks on the surface of Mars would be quite useful. Such searches might be conducted during the present opposition of Mars during the summer of 1986 and, ultimately, at much higher spatial resolution, with the VIMS experiment of the Mars Observer spacecraft.

It has not escaped our attention that the above scenario, if true, could have profound implications for the possible occurrence of life on early Mars and its ultimate survival.

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